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RUNAWAY STARS, TRAPEZIA, AND SUBTRAPEZIA

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RESUMEN

Estudiamos los movimientos internos de las componentes de 44 trapecios tipo OB a partir de las separaciones y ángulos de posición observados a lo largo de 160 años. Encontramos que la mayoría de los trapecios poseen los movimientos internos esperados para cúmulos pequeños, ligados y virializados. Sin embargo, en algunos sistemas encontramos componentes que se escapan. Estudiamos en detalle estas componentes y concluimos que las más veloces pueden ser clasificadas como desbocadas. El número relativamente alto de desbocadas encontrado puede explicarse como resultado de interacciones dinámicas en los sub-trapecios no resueltos que, por analogía a lo que ocurre en el caso del trapecio de Orión, probablemente constituyen las componentes brillantes de nuestra muestra de trapecios.

ABSTRACT

We studied the internal motions of the components of 44 OB trapezium-type systems using all available measures of position angles and separations over a time up to 160 years. We found that most of the trapezia have the internal motions expected for small, bound and virialized clusters. However, in some systems, we detected escaping components. We studied these components in detail and found that the fastest components among them can be classified as runaway stars. The relatively high number of runaways results from the dynamical interactions that occur in the unresolved sub-trapezia, which, in analogy with the Orion trapezium, likely constitute the brightest components of our sample of trapezia.

Key Words: **BINARIES: VISUAL — STARS: EARLY-TYPE — STARS: FORMATION — STARS: KINEMATICS**

1. INTRODUCTION

In this study, we adopted Ambartsumian's (1954) definition of a trapezium. According to him, a trapezium-type multiple system is a multiple star where at least three of the separations between its components are of the same order of magnitude (i.e., their ratio is larger than 1/3 but less than 3). These systems are dynamically unstable, and either evolve towards hierarchical configurations or dissolve by successive ejections of components until only a close pair remains. Internal motions in trapezium-type systems were studied by Allen et al. (1974a), who use data on position angles and separations between the components gathered by a great number of observers. This data span a period up to 130 years for some systems. We found no evidence for an over-all expansion or contraction in these systems. However, we detect a number of trapezia with one or two components which show a significant relative motion. By means of a statistical test and a proper-motion test, the probable membership of the moving stars to their trapezia was established.

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In a later study (Allen et al. 2004) additional data collected between 1974 and 2004 extended the time interval to 160 years for the best studied systems. In studies combining older observations with modern ones, it is indeed important to assign realistic errors to all observations. Fortunately, for the older observations we still had error bars for different observers, estimated by Charles Worley, who later based upon a lifetime of experience dealing with astrometric measures. This study generally confirmed the earlier results. No systematic expansion or contraction was found for any system, and most of the moving companions found earlier were confirmed. We updated the distances and determined anew all transverse velocities. Again, we found that most moving companions have increasing separations. Four stars having transverse velocities large enough to qualify as runaways were found. Table 1, adapted from Allen et al. (2004) summarizes the data.

As well as the previous study, the main problem is to establish that the moving components are not merely optical companions projected in the vicinity of the system. Both the statistical test and the proper-motion test were performed for all moving components, and we devised a new test, based on the luminosity function and the proper motions. These three tests (for details see Allen et al. 2004) lead us to expect at most about 1 optical companion among the 44 systems. We should point out, however, that the proper motion test may reject bona fide physical companions like *AE* Aurigae and μ Columbae.

2. TOO MANY RUNAWAYS?

An important question to be addressed now is whether the number of runaway stars found is not implausibly high. We recall that dynamical ejection from small trapezium-type star clusters is the most likely mechanism to produce runaway stars (Poveda et al. 1967; Leonard & Duncan 1988, 1990; Hoogerwerf et al. 2000 and references therein). This process may also produce low-mass runaway stars. However, dynamical ejection results in one or at most two runaway stars per cluster. The dynamical process is quite violent and rapid, occurring within about 1000 years. Therefore, we must ask whether or not it is plausible to find four runaway stars among 44 trapezia.

Trapezia may also evolve dynamically in a less violent way, if they start out from a virialized state (Allen et al. 1974b). In this case, the time scale for their dynamical evolution is about a million years. These systems also produce escapers, but with low velocities that do not make them runaway stars.

3. TRAPEZIA AND SUB-TRAPEZIA

Recent studies on the Orion trapezium have shown that at least three of its main components (A, B and C) are themselves multiple. For instance, component A is really a triple system. Component C is a hierarchical triple formed by a spectroscopic binary with a 66-day period and a speckle-resolved companion with a period of 10–100 years (Schertl et al. 2003; Vitrishenko 2002). Particularly interesting is θ^1 *Ori* B, which turns out to be a quintuple system (Close et al. 2003). In this case, the separations between some of the components are similar, which indicate that it is an unstable system and may soon eject one ore more companions, perhaps with runaway velocities.

Trapezium-type configurations showing substructure are also found among star-forming regions. In Orion, for instance, the Becklin-Neugebauer (BN) object, the Kleinmann-Low (KL) nebula and their environment form a structure strongly resembling the Orion Trapezium before the UV radiation of θ^1 C cleared away the pre-stellar envelope (Poveda 1977). The 20-micron brightness contours of the Becklin-Neugebauer/Kleinmann-Low (BN-KL) region (Gezari et al. 1998) show a trapezium-like morphology. The projected dimensions of the BN-KL complex ($d \approx 15$ arcsec) and its bolometric luminosity ($L \approx 10^5 L_\odot$) are also quite similar to those of the Orion Trapezium (see Gezari et al. 1998, Fig. 6). Observed at higher resolutions (12.5 micron contours) many embedded faint stars are found (see Shuping et al. 2004, Figures 1 and 2). In fact, the star density in the BN-KL complex is comparable to that of the Trapezium cluster (Shuping et al., 2004). In a recent radioastrometric study of the point sources in the BN-KL complex (Rodríguez et al. 2005) has identified the BN object and the radio source I as an OB runaway star and its recoil object, another OB star, which were produced by dynamical interactions in a sub-trapezium ($d \approx$ 225 AU) about 500 years ago. This is an example of a runaway star having been produced in the last 500 years in a region still obscured by a prestellar envelope.

Another interesting case is that of object JW 451, which has been proposed as a runaway star recently ejected from the Orion Trapezium, likely the component C (Poveda et al. 2005). If this is the case, then component C (today a hierarchical triple) must have been an unstable multiple system, at least quadruple and thus itself a sub-trapezium. This system ejected JW 451 with a transverse velocity of about 70 km/s. It is relevant to note that the binding energy of θ^1 C *Ori* C at present is more than enough to compensate for the kinetic energy of the runaway JW 451, that is, both could have originated in a bound sub-trapezium. In fact, we may now envision the origin of multiple stars as occurring on two scales.

(a) The Orion trapezium (10^4 AU in diameter) is the prototype for the traditional massive unstable multiple systems. Our sample of 44 trapezia would consist of such systems. The BN-KL complex would also belong to this type, although it is still deeply embedded in its pre-stellar envelope. Strong dynamical interactions among the components will produce the high mass OB runaways.

(b) Some of the bright components of the classical trapezia are themselves multiple stars which are composed of less massive stars and move in unstable trajectories of sizes, at least, an order of magnitude smaller than the classical trapezia (that is, 10^2 to 10^3 AU). The best examples of these subtrapezia are:

1. θ^1 *Ori* C, with three components, plus JW 451 before it was ejected.

2. θ^1 *Ori* B, with five components.

TABLE 1

TRAPEZIA WITH PROBABLE MEMBERS SHOWING LARGE TRANSVERSE VELOCITIES

ADS	Moving Component	Spectrum	Distance[a] pc	Mv(A)	Mv(LTV)[b] $.''/100$y	ds/dt km s^{-1}	V_t
2843	AD	B1 I ab	301[2]	−4.5	3.1	6.60	99.0
13374	AC	WN5+ 09.5 III	1600[3]	−4.2	−0.2 .	3.24	259.0
15834	AB	09V	3467[1]	−3.3	−3.0	0.36	62.4
15847	AC	B5 IV	392[2]	−2.6	3.6	5.90	115.0

[a]References for distance: (1)Abt & Corbally 2000; (2) Hipparcos: ESA 1997; (3) Rubin et al. 1962, van der Hucht 2001.

[b]LTV: Large Transverse Velocity.

3. The multiple system BN-KL + IRc2, with three or more components before it broke apart.

Clearly, the existence of these subtrapezia will considerably increase the rate of production of less-massive runaways like the ones we have identified and shown in Table 1.

4. CONCLUSIONS

We have found internal motions of trapezium systems to be generally small (or even below the observational errors), which is consistent with these systems, being gravitationally bound. However, in a few cases, we found stars to be escaping, some of them with velocities high enough to identify them as recently formed runaway stars, but not as optical companions. By means of three tests, we estimate that the number of such optical companions remaining among the 44 systems studied is less than one. Some of these runaway stars are undoubtedly formed in the classical collapsing trapezia. We hypothesize that others are dynamically ejected from the subtrapezia into which many of the trapezium components appear to resolve when they are observed at high resolution. Since these substructures appear to be dynamically unstable, ejection of runaway stars from them appears quite likely. Thus, in the Orion trapezium cluster we are witnessing the recent production of two runaway stars, one per trapezium, and both within the last 1000 years. They are separated by only about 60 arcsec. Therefore, the fact that we have detected four runaway stars among our sample of 44 trapezia is worthwhile.

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